

ULTRA-THIN SI CHANNEL CMOS WITH IMPROVED
SERIES RESISTANCE

DESCRIPTION

BACKGROUND OF THE INVENTION

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Field of the Invention

10 The present invention generally relates to the manufacture of transistors for integrated circuits and, more particularly, to the production of complementary pairs of field effect transistors of enhanced performance at extremely small scale.

Description of the Prior Art

15 Performance and economic factors of integrated circuit design and manufacture have caused the scale of elements (e.g. transistors, capacitors and the like) of integrated circuits to be drastically reduced in size and increased in proximity on a chip. That is, increased integration density and proximity of elements reduces the signal propagation path length and reduces signal propagation time and susceptibility to noise and increases possible clock rates while the reduction in element size necessary for increased integration density increases the ratio of functionality which can be provided on a chip to the costs of production (e.g. wafer/chip area and process materials) per chip and, 20 potentially, the cost of devices containing the chips by reducing the number of inter-chip and inter-board connections required. 25

In response, many improvements in transistor design have been made to maintain suitable levels of performance of these elements, for example, lightly doped drain (LDD) structures (now generally referred to as extension implants since heavier doping levels have been required in current minimum feature size regimes), halo implants and graded impurity profiles have been employed to counteract short channel and punch-through effects and the like, particularly in field effect transistors (FETs) which have become the active device of choice for all but the highest frequency devices. Reduction in device scale has also required operation at reduced voltages to maintain adequate performance without device damage even though operating margins may be reduced.

Thin silicon channel Si devices are becoming a promising option to continue SOI CMOS scaling. It has the advantage of sharper sub-threshold slope, high carrier mobility (because the device is operated at a lower effective field), and better short channel control. Although these attributes are highly desirable, thin silicon channel Si devices have significant disadvantages that could hinder further SOI CMOS scaling. The primary disadvantage is that as the SOI film is thinned, the series resistance increases.

In some prior art thin Si channel devices, the extensions are implanted prior to raised source-drain (RSD) formation. RSD is used to reduce series resistance by increasing the Si thickness outside the channel region. This causes at least two problems. The first problem is that since the pFET extension requires a fairly thick offset spacer, a high resistance region exists under the spacer. The

second problem is that since the extension implants are performed prior to the RSD process, the dopants are subjected to the significant thermal budget of the RSD process. This can cause unwanted diffusion of the dopants. In addition, the incubation time (e.g. anneal time) is different for p and n type Si which leads to substantially different RSD thickness for pFET and nFET. Also, the surface concentration of the dopants must be uniform across the wafer as well as from wafer to wafer, which is a major challenge, if the RSD process is to be manufacturable.

In another prior art thin Si channel device, a disposable spacer is used. A wide disposable spacer is used to grow the RSD. Next the deep source and drain implants are done. After this, the spacer is removed, and the extensions are implanted. Although the disposable spacer scheme overcomes the problem of subjecting the extensions to the RSD thermal budget, this process does not overcome the problem of the high-resistance region outside the RSD layer. Accordingly, it is clear that a need exists for a method to overcome the high resistance problem as well as the thermal budget problem.

Typically a trade-off exists between short channel effect control and high current. Specifically, an optimal performance nFET 100 is achieved using a small spacer 121a as shown in Figure 1g while the optimal pFET 200 has a much larger spacer 221b as shown in Figure 1h. This is due to the fact that the diffusivity of boron is significantly higher than that of arsenic: the materials used in the pFET 200 and nFET 100 gate areas 122, 222, source and drain regions 128, 228,

and extensions 125, 225 respectively. The halo regions 124, 224, however, are boron in the nFET 100 and arsenic in the pFET 200. As shown in Figure 1g, the boron source and drain regions 228 and extensions 224 of the pFET 200 are diffused greatly during the anneal process thereby creating the short channel effect in the pFET unless a thick spacer is used. The nFET 100 is largely unaffected by the anneal, with the exception of the halo regions 124 diffusing slightly. The nFET 100 performs very well when manufactured using thin offset spacers 121a. Figure 1h shows how performing the manufacturing process using thick spacers 121b, 221b improves the pFET 200 performance by avoiding the short channel effect, as the source and drain regions 228 are implanted further out from the channel. When annealed, the boron implants 228, 225 diffuse to a beneficial placement. However, the arsenic source and drain regions 128 of the nFET 100 do not adequately diffuse yielding poor performance and a high level of resistance under the thick spacer. Thus, a need exists for an ultra-thin Si MOSFET having a smaller offset for nFET compared to pFET on the same wafer. Such a configuration, however, has not been practical due to the increase of process steps to form spacers of different thicknesses.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a method for simultaneously achieving CMOS devices on ultra-thin Si channels having improved series resistance, extensions undergoing low thermal budget processing and independent pFET and nFET offset.

It is another object of the invention to provide a method and structure to produce a high performance pFET and nFET device on the same wafer.

It is another object of the invention to allow the silicide to be significantly closer to the channel region thereby increasing the electron mobility and providing lower external resistance.

In order to accomplish these and other objects of the invention, a method of improving the performance of different semiconductor conductivities on the same wafer will be provided comprising steps of fabricating thin spacers on a wafer, forming raised source-drain regions by selective epitaxy, depositing a hard mask film across the wafer, forming a block mask over a first transistor, removing the block film stack from a second transistor, removing said block mask over the first transistor, performing additional selective epitaxial growth affecting only the areas of the second transistor as the block film stack covering the first transistor is resistant to the additional epitaxial procedure, and performing extension implants to the first and/or second transistor.

Additionally, a semiconductor apparatus will be provided comprising a MOSFET device including Si wafer thinning, isolation, gate dielectric, and gate

stack patterning, a first transistor, a second transistor, thin sidewall spacers, a thin epitaxial Si layer in the extension region of the first transistor, and a thick epitaxial Si layer in the extension region of the second transistor.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

Figures 1a-1f show a schematic cross-section of the method and structure of the prior art.

Figure 1g shows a CMOS transistor pair using a thin offset spacer.

Figure 1h shows a CMOS transistor pair using thick offset spacers.

Figure 2 is a cross-sectional representation of an SOI wafer having undergone device isolation, gate dielectric processing and gate stack patterning using processes well known in the art.

Figure 3 is a cross-sectional representation of the CMOS pair after thin spacers are formed using standard deposition and spacer etch procedure.

Figure 4 is a cross-sectional representation of the CMOS pair after RSD is formed by selective epitaxy.

Figure 5 is a cross-sectional representation of the CMOS pair after a hard mask film is deposited across the entire wafer.

Figure 6 is a cross-sectional representation of the CMOS pair after a block mask is formed over the nFET regions.

Figure 7 is a cross-sectional representation of the CMOS pair after the hard mask is removed from the pFET regions and the lithography is removed from the nFET regions.

Figure 8 is a cross-sectional representation of

the CMOS pair after a selective epitaxial growth process is carried out.

Figure 9 is a cross-sectional representation of the preferred embodiment of the CMOS pair as extensions are implanted to the pFET region of the Si substrate.

Figure 10 is a cross-sectional representation of the CMOS pair as the hard mask is removed from the nFET regions following Figure 8.

Figure 11 is a cross-sectional representation of the CMOS pair after a block mask is applied to the pFET regions and nFET extensions are implanted.

Figure 12 is a cross-sectional representation of the CMOS pair where the block mask is removed from the pFET regions and another block mask is defined over the nFET regions while pFET extension implants are performed.

Figure 13 is a cross-sectional representation of the CMOS pair after the block mask is removed from the nFET region illustrating an alternate embodiment of the device structure.

Figure 14 is a cross-sectional representation of the CMOS pair in another alternate embodiment using optional second spacers to prevent silicide bridging without performing the optional deep source-drain implants.

Figure 15a, 15b, and 15c are cross-sectional representations of the CMOS pair in another alternate embodiment using optional deep source-drain spacers to form source-drain implants with the final device structure shown in Figure 15c.

DETAILED DESCRIPTION OF A PREFERRED
EMBODIMENT OF THE INVENTION

Referring now to the drawings, and more particularly to Figures 1a-1f, a method over which the invention provides improvements is shown for forming a CMOS pair. Figures 1a-1f are arranged to provide an enhanced understanding of the invention and no portion thereof is admitted to be prior art as to the present invention. The process shown in these steps exhibits particular deficiencies which the present invention successfully avoids. More specifically, Figure 1a is a cross-sectional view of an SOI device including an Si substrate 16, isolation layer 17, oxide layer 18, gate dielectrics 122, 222, and a patterned gate stacks 120, 220. Figure 1b illustrates the next step in this process, where spacers 121 are formed in the nFET region 100 and spacers 221 are formed over the pFET region 200. The pFET region 200 is protected using a block out mask 223 while the nFET region 100 has extensions 125 and halos 124 implanted. The mask 223 is removed from the pFET region 200 and another block mask 123 is applied to the nFET region 100 while extensions 225 and halos 224 are implanted within the pFET region 200, as shown in Figure 1c. After the nFET and pFET extensions 125, 225 are implanted, and a rapid thermal anneal (RTA) process is carried out to remove implant damage thereby reducing transient enhanced diffusion during the raised source and drain (RSD) process. After the anneal, a pre-clean is performed after which the RSD formation is done, and the resulting structure shown in Figure 1d. Having the extensions 125, 225 implanted prior

to the RSD formation can cause at least two problems; (1) the pFET extension 225 requires a fairly thick offset spacer as a high resistance region exists under the spacer, and (2) the dopants used in the extension implants are subjected to the significant thermal budget of the RSD process which can cause unwanted diffusion of the dopants which increases undesirable the short channel effects. The short channel effect may be improved by increasing the spacer thickness. However, this also increases the series resistance for the ultra-thin Si channel device. If the RSD process is to be manufacturable, the surface concentration of the dopants must be uniform across the wafer as well as from wafer to wafer, which becomes a major challenge as excessive RSD thickness can lead to unwanted bridging between isolated Si regions.

Additionally, incubation times differ for p and n type Si which leads to substantially different RSD thickness for the pFET 200 and nFET 100 which can also lead to yield and performance issues. Continuing on to Figure 1e, illustrating the next step in this process of SOI CMOS formation, large spacers 126, 226 are formed and another block mask 229 is formed over the pFET regions 200 while the nFET source-drain regions 128 are implanted. Figure 1f shows the block mask 229 removed and another mask 129 applied to the nFET regions 100 as pFET extensions 225 are implanted.

Referring now to Figure 2, there is shown, in cross-section, an exemplary pair of complementary nMOS 100 and pMOS 200 transistors such as might comprise a CMOS pair in a portion of an integrated circuit. These transistors have been completed

through the formation of shallow trench isolation gate oxidation and gate stack patterning and are substantially the same as is shown in Figure 1a. The method of formation of these transistors and the particulars of their structures are unimportant to an understanding of the invention or its successful practice. It should be understood that while Figure 2 illustrates transistors prior to the application of the invention thereto, the illustration is intended to be highly schematic for clarity and no portion of Figure 2 is admitted to be prior art as to the invention.

A thin spacer 130, 230 is fabricated using standard deposition and spacer etch procedure, the resulting structure after this step is shown in Figure 3. A thin SiO₂ liner may be deposited prior to a SiN film followed by a SiN spacer etch. The combination of SiO₂ and SiN thicknesses should be small, preferably in the range of 3-15 nm since this thickness defines the region of high resistance formed by the thin Si directly outside the channel. This region may be thinner than the channel due to the Si recess caused by the gate stack etch.

Referring now to Figure 4, RSD 27 is formed by selective epitaxy. Unlike the RSD process shown in Figure 1d, the extension implants 125, 225 are not yet present, and therefore are not subjected to the thermal budget of the RSD process. Thus, unwanted diffusion is avoided.

At this point in the process, a hard mask 31 consisting of SiO₂ and possibly SiN is deposited on the entire wafer, as shown in Figure 5. A block mask 132 is then formed over the nFET regions by conventional lithography as shown in Figure 6. The

block-out mask 132 is used to selectively remove the hard mask 231 from the pFET regions 200 of the wafer. The hard mask 231 may be removed by a dry or wet etching or a combination of dry or wet etching. After the selective film 231 removal and lithography mask 132 removal, the resulting structure is shown in Figure 7. As shown, the hard mask 131 is still present over the nFET regions 100.

Referring now to Figure 8, following a pre-clean which removes any contamination from the pFET region 200, an additional selective epitaxial growth process is carried out. Since the growth process is selective to the hard mask material 131, growth is achieved on the pFET region 200 but not the nFET region 100 of the wafer.

This step is very important to the understanding of the invention. In conventional CMOS devices, optimal performance for an nFET is achieved using a small spacer while the pFET requires a large spacer for optimal performance. This is largely due to the diffusion rate differences exhibited by arsenic and boron, located in the gate areas 120 and 220 of the nFET 100 and pFET 200 respectively, as the diffusivity of boron is significantly higher than that of arsenic. For conventional ultra-thin devices, the smaller spacer can be used to optimize the nFET, however, pFET short channel effect is compromised. If a large offset spacer is used, then the external resistance is high for both devices, resulting in no real overall gain. Further, chip space is consumed and the overall size of a (e.g. complementary) pair of transistors is increased. However, using the method and structure of the current invention, both the

nFET and pFET can be optimized simultaneously on the same wafer by the growth process noted above which provides additional thickness for the pFET RSD 227. In doing so, CMOS devices can be made more efficient while maintaining current size, or can maintain an efficiency comparable to current CMOS devices but in a smaller footprint since the source and drain regions need be no larger than is required for a contact.

In a preferred embodiment, the hard mask film 131 is suitably thick and the pFET extension implant energy 36 is sufficiently low, then pFET extensions 225 and halos 224 may be implanted as shown in Figure 9. If the implantation process is done under these conditions, then no additional mask steps are required to achieve this unique device structure. However, additional thickness of hard mask film may be used if desired or needed.

In an alternate embodiment, the hard mask film 131 is removed from the nFET regions by an etching procedure, the result shown in Figure 10. Next a block mask 233 is defined by a conventional lithography procedure for the purpose of protecting the pFET regions 200 from the nFET extension implanting energy 37. The nFET extensions 125 are then implanted as shown in Figure 11. It is important to note that the RSD thickness may be used to adjust the effective offset of the nFET extension 125 from the gate edge but in the vertical rather than horizontal direction. Additionally, another implant with a different energy and dose may be used to provide optimized contact resistance for silicide.

Next, the block mask 233 is removed from the

pFET regions 200 and another block mask 133 is defined over the nFET regions 100. The pFET extension implant is then performed as shown in Figure 12. The RSD 227 thickness on the pFET regions may be adjusted to provide optimal offset for the pFET extension implant 225. Additionally, another implant with a different energy and dose may be used to provide optimized contact resistance for silicide. Substantial process simplification may be achieved by optimizing the implants, and independently, the RSD thickness for pFET 227 and nFET 127 to provide independent offsets for extension implants 125, 225. The final device structure of this alternate embodiment is shown in Figure 13.

A perfecting feature of this embodiment is the addition of a deep source-drain spacer 134, 234 as shown in Figure 14. This second spacer may be used as a silicide spacer to prevent silicide bridging.

A further perfecting feature uses the deep source-drain spacers 134, 234 to perform source-drain implants 128, 228. More specifically, the nFET regions 100 are covered with a block mask 135 as pFET source-drain implants 228 are formed as shown in Figure 15a followed by nFET source-drain implants 128 while pFET regions 200 are protected by block mask 235 as shown in Figure 15b. The resulting structure is shown in Figure 15c.

In view of the foregoing, a method and structure are provided in order to produce a thin silicon channel SOI CMOS of high performance on a single wafer. In this invention, the silicide can also be closer to the channel region which can increase electron mobility and provide lower

external resistance.

While the invention has been described in terms of a single preferred embodiment, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the disclosed invention.